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ARTIFICIAL INTELLIGENCE IN MANAGING LOGISTICS COSTS OF THE AGRO-INDUSTRIAL COMPLEX

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Abstract. The study examines artificial intelligence not as a general digitalisation factor, but as a tool for management accounting and operational control of logistics costs in the agro-industrial complex. The relevance stems from the spatial dispersion of agricultural production, seasonality, perishability, high transport intensity, and the growing need to integrate accounting data with real-time logistics information. The aim is to develop a cost-control framework that identifies where AI affects total logistics cost and what accounting indicators should be used to measure this effect. The empirical context is based on official data on Kazakhstan's transport and agricultural digitalisation in 2025–2026, OECD materials, and peer-reviewed studies of AI in supply chain management and agri-food systems. The methodological design combines secondary data analysis, functional decomposition of logistics costs, cost-driver mapping, plan–fact variance analysis, and process-based modelling. The article distinguishes six cost blocks: transportation, warehousing, inventory holding, handling, product losses, and administrative and information costs. A three-level analytical framework is proposed: operational event → cost driver → financial indicator. On this basis, an AI-enabled logistics cost control architecture is developed in which

ERP/TMS/WMS/IoT data feed forecasting, anomaly detection and optimisation algorithms. At the same time, the output is evaluated through accounting KPIs rather than technological metrics alone. Current data from Kazakhstan show that 648 agricultural producers already use digital technologies and AI-related tools, while the e-Agriculture ecosystem is moving toward integrated data management and sectoral AI analytics. The practical contribution is a methodology for selecting AI use cases based on their expected impact on specific cost drivers and for integrating AI outputs into management accounting and logistics control.

Keywords: agro-industrial complex, logistics costs, cost accounting, artificial intelligence, digital transformation, supply chain management, logistics control

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АГРОӨНЕРКӘСІПТІК КЕШЕННІҢ ЛОГИСТИКАЛЫҚ ШЫҒЫНДАРЫН БАСҚАРУДАҒЫ ЖАСАНДЫ ИНТЕЛЛЕКТ

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Аннотация. Зерттеуде жасанды интеллект цифрландырудың жалпы факторы ретінде емес, агроөнеркәсіптік кешеннің логистикалық шығындарын басқару есебі мен жедел бақылау құралы ретінде қарастырылады. Өзектілігі ауыл шаруашылығы өндірісінің аумақтық дисперсиясына, маусымдылығына, өнімнің тез бүлінуіне, жоғары көлік сыйымдылығына және нақты уақыт режимінде логистикалық ақпаратпен есептік деректерді біріктіру қажеттілігіне байланысты. Зерттеудің мақсаты — жасанды интеллект жиынтық логистикалық шығындардың қандай элементтеріне әсер ететінін және осы әсерді қандай есептік көрсеткіштермен өлшеу керектігін анықтауға

мүмкіндік беретін шығындар мен бақылау әдістемесін жасау. Эмпирикалық контекст Қазақстанның 2025-2026 жылдардағы Ауыл шаруашылығын тасымалдау және цифрландыру туралы ресми деректері, OECD материалдары және жеткізу тізбектері мен агроазық-түлік жүйелерін басқарудағы AI рецензияланатын зерттеулері негізінде қалыптастырылды. Әдістемелік дизайн қайталама деректерді талдауды, логистикалық шығындардың функционалды ыдырауын, шығындар драйверлерін картаға түсіруді, нақты ауытқуларды талдауды және процестік модельдеуді біріктіреді. Шығындардың алты блогы бөлінді: тасымалдау, сақтау, қорларды ұстау, жүк өңдеу, өнімнің жоғалуы және әкімшілік-ақпараттық шығындар. "Операциялық оқиға → шығындар драйвері → қаржылық көрсеткіш" үш деңгейлі аналитикалық схема ұсынылған. Осы негізде логистикалық шығындарды AI бақылау архитектурасы әзірленді, онда ERP/TMS/WMS/IoT деректері болжау, ауытқуларды анықтау және оңтайландыру алгоритмдерімен пайдаланылады және нәтиже KPI есептік жазбалары арқылы бағаланады. Қазақстанның өзекті деректері көрсеткендей, 648 ауыл шаруашылығы тауарын өндірушілер қазірдің өзінде цифрлық технологиялар мен аі элементтерін пайдалануда. Практикалық нәтиже нақты шығындар драйверлеріне күтілетін әсер ету және AI нәтижелерін Басқару есебі мен логистикалық бақылауға қосу үшін AI жағдайларын таңдау әдістемесінен тұрады.

Түйін сөздер: агроөнеркәсіптік кешен, логистикалық шығындар, шығындар есебі, жасанды интеллект, цифрлық трансформация, жеткізу тізбектерін басқару, логистикалық бақылау

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ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ В УПРАВЛЕНИИ ЛОГИСТИЧЕСКИМИ ИЗДЕРЖКАМИ АГРОПРОМЫШЛЕННОГО КОМПЛЕКСА

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Аннотация. В исследовании искусственный интеллект рассматривается не как общий фактор цифровизации, а как инструмент управленческого учета и оперативного контроля логистических издержек агропромышленного комплекса. Актуальность обусловлена территориальной рассредоточенностью сельскохозяйственного производства, сезонностью, скоропортимостью продукции, высокой транспортной емкостью и необходимостью интеграции учетных данных с логистической информацией в режиме реального времени. Цель исследования – разработать затратно-контрольную методику, позволяющую определить, на какие элементы совокупных логистических издержек воздействует искусственный интеллект и какими учетными показателями должен измеряться данный эффект. Эмпирический контекст сформирован на основе официальных данных о транспорте и цифровизации сельского хозяйства Казахстана за 2025–2026 гг., материалов OECD и рецензируемых исследований AI в управлении цепями поставок и агропродовольственных системах. Методический дизайн объединяет анализ вторичных данных, функциональную декомпозицию логистических издержек, картирование драйверов затрат, анализ план–фактных отклонений и процессное моделирование. Выделены шесть блоков затрат: транспортировка, складирование, содержание запасов, грузообработка, потери продукции и административно-информационные расходы. Предложена трехуровневая аналитическая схема «операционное событие → драйвер затрат → финансовый показатель». На этой основе разработана архитектура AI-контроля логистических издержек, в которой данные ERP/TMS/WMS/IoT используются алгоритмами прогнозирования, выявления аномалий и оптимизации, а результат оценивается через учетные KPI. Актуальные данные Казахстана показывают, что 648 сельхозтоваропроизводителей уже используют цифровые технологии и элементы AI. Практический результат состоит в методике отбора AI-кейсов по ожидаемому воздействию на конкретные драйверы затрат и включения результатов AI в управленческий учет и логистический контроль.

Ключевые слова: агропромышленный комплекс, логистические издержки, учет затрат, искусственный интеллект, цифровая трансформация, управление цепями поставок, логистический контроль

Introduction. For the agro-industrial complex, logistics is the area where technological, natural-climatic, and market risks are directly transformed into financial results. The same batch of agricultural products consistently generates costs for loading, transportation, storage, maintaining temperature conditions, insuring stocks, sorting, and providing information support. If delivery time increases or the demand forecast proves inaccurate, the enterprise faces not only transportation overruns but also increased inventory, additional storage, quality declines, and write-offs. Therefore, managing logistics costs in the agro-industrial complex requires analysing their causes at the process and event level, rather

than merely recording the final amount in accounting records (Mizanbekov et al., 2023; Abdimoldayeva et al., 2025). The problem is particularly significant for Kazakhstan. In 2025, the country's transport sector handled 1,163.6 million tonnes of cargo, and cargo turnover reached 584.3 billion tonne-kilometres, up 7.9% and 13.6%, respectively, from 2024 (Bureau of National Statistics, 2026). Growth in physical flow increases the need for route planning, loading, warehouse capacity, and faster information processing. For agriculture, this is compounded by seasonal peaks, the spatial remoteness of producers, and differences in regional transport accessibility.

The digitalisation of Kazakhstan's agricultural sector has already moved from separate information systems to a unified data architecture. According to the Ministry of Agriculture, 648 agricultural producers use digital technologies and elements of artificial intelligence: 396 farms in crop production, 211 in livestock farming, and 41 in processing. More than 200 farms are classified as Smart farms. In 2025, an updated map of the digital transformation of the agro-industrial complex was approved, including the digitisation of 144 business processes; the strategic objective for 2026 is the creation of a unified ecosystem of the e-agro-industrial complex and industry Data Lake (Ministry of Agriculture of the Republic of Kazakhstan, 2026a; 2026b).

International literature confirms the expansion of AI functions in supply chains. While early studies focused on forecasting and automation, modern research views AI as a decision-making infrastructure that integrates demand forecasting, inventory optimisation, routing, quality monitoring, anomaly detection, and risk management (Toorajipour et al., 2021; Richey et al., 2023; Shahzadi et al., 2024). In agri-food chains, this area has been supplemented with tasks such as traceability, monitoring storage conditions, and reducing product losses (Guidani et al., 2024; Reitano et al., 2025; Sebti et al., 2026).

However, the technological effect is not equivalent to the financial one. The algorithm may improve forecast accuracy, but in management accounting it is necessary to answer another question: which cost deviation was prevented, in which cost centre it occurred, and which driver changed. Spreitzenbarth et al. (2024) showed that intelligent cost analysis in purchasing and supply management remains less researched than other AI use cases, despite its high practical interest to companies. In agricultural logistics, this gap is exacerbated by the fact that some losses manifest physically as reductions in product weight or quality. However, economically, they stem from logistics decisions.

Studies in Kazakhstan also demonstrate the gap between digitalisation and cost accounting. Abdimoldayeva et al. (2025) highlight the need to identify logistics processes and to apply modern cost distribution methods. Smagulov et al. (2025) link the digitalisation of food logistics to infrastructure modernisation, monitoring, and data-based resource management. Tsapova et al. (2025) identify AI, robotics, and geospatial technologies as key drivers of digital modernisation in Kazakhstan's agricultural sector. At the same time, the methodology that combines AI analytics

with the plan–actual control system for logistics costs remains insufficiently developed.

The study aims to develop a methodology for managing logistics costs in the agro-industrial complex, in which AI forecasting and optimisation results are translated into the management accounting system through cost drivers and financial KPIs. The research hypothesis is that the economic effect of AI in agro-logistics arises only when two conditions are met: the algorithm is linked to a controlled operational driver, and changes in this driver are reflected in the cost accounting system. The scientific novelty lies in the development of a three-level scheme "operational event → cost driver → financial indicator" and an AI-enabled logistics cost control architecture designed for planning, monitoring, and subsequent analysis of deviations.

Literature review. The study's theoretical foundation sits at the intersection of three areas: supply chain management, management accounting of logistics costs, and the application of artificial intelligence. Toorajipour et al. (2021) showed in a systematic review that the most stable areas of AI application are forecasting, planning, inventory management, and interactions among chain participants. Richey et al. (2023) emphasise that AI is changing the logistics decision-making process itself, enabling a shift from periodic analytics to the continuous processing of streaming data.

Shahzadi et al. (2024), drawing on 68 publications and an extended TOE logic, systematise the technological, organisational, external, and human factors influencing AI adoption. This conclusion is directly relevant to the analysis of logistics costs: the same algorithm does not yield the same financial outcome if a company lacks comparable data, integrated information systems, and specialists who can interpret the results. Therefore, AI should be included in the management control system only together with data governance mechanisms.

From a cost management perspective, the transition from classifying technologies to classifying economic effects is important. Spreitzenbarth et al. (2024), in a mixed-methods study on purchasing and supply management, identified 11 AI/ML use-case clusters and found a discrepancy between academic attention and practitioners' assessments: cost analysis and supplier sustainability have greater practical potential than publication intensity suggests. This confirms the need for independent analysis of cost-related AI cases.

Costs in agri-food chains also depend on biological and temporal factors. Rejeb et al. (2025) demonstrate the growing use of machine learning in the agricultural supply chain for monitoring, forecasting, resource management, and risk identification. Reitano et al. (2025), based on a systematic review of the entire agri-food supply chain, note that AI increases the efficiency of production and intermediate operations. However, limited access to technology, data quality, and competencies limits implementation.

Research on digital twins is developing process-based management logic. Guidani et al. (2024) proposed a holistic digital twin of the agri-food chain, covering

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production, processing, storage, and distribution, and enabling the assessment of economic and logistics indicators for a specific order. Tzachor et al. (2022) view digital twins as a tool for transforming agri-food production systems and chains. In management accounting, a digital twin's value lies in its ability to assess the consequences of an alternative route, inventory plan, or capacity utilisation before an operation is carried out.

Sebti et al. (2026) analyse RFID, IoT, blockchain, and AI as complementary technologies for traceability in agri-food chains. Traceability creates a digital record of events: batch arrival, temperature changes, movement, delays, and transfers of responsibility. In traditional accounting, such events are often aggregated after the fact, whereas AI enables their use as early indicators of future costs. Therefore, data traceability should be considered the informational basis for cost traceability.

The specifics of Kazakhstan form a distinct research context. Mizanbekov et al. (2023), using grain transportation in Northern Kazakhstan as an example, demonstrate the significance of loading factors, cargo turnover, and route for transportation costs. Smagulov et al. (2025) emphasise the need for digital platforms in food logistics. Tsapova et al. (2025) link the effectiveness of digital modernisation of the agro-industrial complex to the implementation of precision farming, geospatial technologies, robotics, and AI. OECD (2025) notes that Kazakhstan is integrating agricultural information systems into a single e-Agriculture platform, including a new system for tracking crop production.

The work by Abdimoldayeva et al. (2025), which directly addresses accounting for logistics costs in the agro-industrial complex, is of key importance. This study continues this line of research but shifts the focus of analysis from cost classification and accounting to the mechanism of operational management: how a digital event and an AI signal should be transformed into a corrective action and then into a measurable plan–actual effect.

Thus, the literature has sufficiently developed AI's technological functions and the industry-specific features of agri-food chains. However, the interface between AI analytics and management accounting remains underexplored. This interface should enable four actions: identify the cost driver, establish a basic standard, link the AI solution to a change in the driver, and measure the financial deviation. It is precisely this research gap that determines the methodological design of the work.

Materials and methods. The study was conducted as an analytical and methodological study, using secondary empirical data. Unlike survey-based studies, the article does not create an artificial sample of enterprises and does not attribute quantitative effects to AI that are not confirmed by the observed data. The information base includes official statistics of the Republic of Kazakhstan on transport for 2025; data from the Ministry of Agriculture on the implementation of digital technologies and AI in 2025–2026; OECD Agricultural Policy Monitoring and Evaluation 2025; peer-reviewed studies on AI in SCM, agri-food logistics, and logistics cost accounting.

The study was carried out in four stages. In the first stage, we developed a

functional decomposition of total logistics cost (TLC). TLC includes transportation costs TC, warehouse costs WC, inventory holding costs IC, cargo handling costs HC, logistically caused product losses LC, and administrative and information costs AIC:

$$TLC = TC + WC + IC + HC + LC + AIC. \quad (1)$$

This representation differs from aggregated accounting in that product losses are considered an independent object of logistical control. For perishable products, reductions in weight, quality, or shelf life may directly result from delays, routing errors, temperature-regime violations, or excessive storage.

In the second stage, we applied cost driver mapping. For each expense category, an operational event, a physical driver, an accounting indicator, and a potential AI function were identified. The basic analytical unit takes the form:

$$\text{Operational event} \rightarrow \text{cost driver} \rightarrow \text{cost centre} \rightarrow \text{financial KPI} \rightarrow \text{AI signal}. \quad (2)$$

For example, the event "vehicle delay" changes the driver "machine-hours of downtime," is reflected in the transportation cost centre, and affects the cost per ton-kilometer and the cost of delivering the shipment. An AI signal can use congestion prediction, telemetry, and dynamic routing. Unlike the general metric "algorithm accuracy," this scheme enables measurement of the financial impact.

At the third stage, an analysis of plan–actual deviations was used. For any category of logistics costs, the actual deviation can be decomposed into the price of the resource, the volume of the operation, the efficiency of resource use, and losses:

$$\Delta C = \Delta C_{price} + \Delta C_{volume} + \Delta C_{efficiency} + \Delta C_{loss.} \quad (3)$$

Artificial intelligence primarily affects efficiency and loss components by reducing unproductive mileage, waiting time, excess inventory, emergency downtime, and write-offs. Price fluctuations in fuel, tariffs, and resources cannot be automatically attributed to AI. This distinction prevents overestimating digital projects.

In the fourth stage, an AI-enabled logistics cost-control architecture was developed. In it, AI is considered an analytical layer between operational systems and management accounting. Data sources include ERP, TMS, WMS, IoT/GPS, and traceability systems; AI models perform forecasting, anomaly detection, and optimisation; the result informs management decisions, and performance is assessed using plan–fact KPIs.

To describe the current level of digitalisation in Kazakhstan, we applied a descriptive analysis of official data. Of the 648 agricultural producers using

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digital technologies and AI elements, the sectoral structure was calculated: crop production - 61.1%, livestock farming - 32.6%, processing - 6.3%. These shares are not a representative assessment of digitalisation across the entire agro-industrial complex, since the official source covers only enterprises that already use these technologies.

The methodology's limitations stem from the lack of a single open micro-database of logistics costs for agro-industrial enterprises. Therefore, the article does not build a regression with fictional coefficients and does not claim a specific percentage reduction in cost. The proposed methodology is intended for subsequent testing on ERP/TMS/WMS data from specific enterprises and can serve as the basis for a panel or quasi-experimental study.

Disclosure of the use of generative AI. OpenAI ChatGPT (GPT-5.6 Sol) was used for language editing, text structuring, and technical formatting of the manuscript. The tool was not used to create fictitious empirical observations or to substitute statistical calculations; the authors are responsible for the scientific content, source verification, and the final version.

Results. The first result concerns the formation of a system of control objects. In traditional financial accounting, logistics costs may be distributed across several items and departments, so the manager sees the final amount but not always the reason for its change. AI-based control requires a more detailed link between operational events and costs.

Table 1 — Accounting objects and drivers of logistics costs in the agro-industrial complex

Cost block	Typical cost centre:	Main driver	Financial KPI:	AI-функция
TC – transportation	transport/ delivery;	km, t-km, machine-hours, loading	costs per ton-km; costs per batch	route optimisation; ETA prediction
WC – warehousing	warehouse/ refrigeration;	pallet-days, t-days, kWh	cost of storing 1 ton-day	capacity forecast; energy optimisation
IC – inventory	raw material / finished product inventory;	average stock, days on hand	cost of capital; turnover	demand forecast; inventory optimisation
HC – cargo handling	loading/sorting;	operations, minutes, labour hours	cost of a single operation	computer vision; task scheduling
LC – product loss	quality/write-offs;	kg/t of losses, hours of mode deviation	cost of write-offs; loss rate	quality prediction; anomaly detection
AIC – information and administrative cost expenses	dispatch/ accounting.	transactions, manual operations	transaction cost; decision time	NLP; document automation
Note: developed by the authors based on Mizanbekov et al. (2023), Spreitzenbarth et al. (2024), Reitano et al. (2025), and Abdimoldayeva et al. (2025).				

The second result is the distinction between technological and financial effects. For example, an increase in ETA accuracy is not an economic result in itself. An economic result arises if a more accurate ETA reduces unloading waiting time,

reduces excess downtime, and is reflected in the cost per machine hour or the cost of shipping the batch. Similarly, improving demand forecast accuracy is important for accounting only when it leads to changes in average inventory, write-offs, or the frequency of urgent shipments.

Table 2 — Translating AI technological metrics into management accounting indicators

AI case	Technological metric	Intermediate driver	Financial indicator
Demand forecasting	MAPE / MAE	stock level; shortage frequency	IC per unit of product; stockout cost
Routing	ETA accuracy	km; downtime; loading	TC/t-km; TC/batch
Predictive maintenance	precision/recall of failures	hours of unplanned downtime	downtime cost; urgent repair
Cold chain control	the proportion of detected anomalies	time outside the permissible range	LC; write-off cost
Computer vision	recognition accuracy	sorting/picking errors	HC/operation; return cost
NLP/GenAI in documents	the proportion of automation	minutes of manual processing	AIC/transaction
Note: the author's classification is based on Richey et al. (2023), Shahzadi et al. (2024), and Rejeb et al. (2025).			

The third result describes the current state of digitalisation in Kazakhstan's agro-industrial complex. The Ministry of Agriculture reports 648 farms that use digital technologies and AI elements. Within this group, 396 farms are involved in crop production, 211 in livestock farming, and 41 in processing. This means that the current wave of digitalisation is most evident in primary production, whereas the processing segment is significantly less represented. For logistics control, this matters because maximum impact requires integrating data across production, processing, storage, and transportation, rather than digitalising a single link.

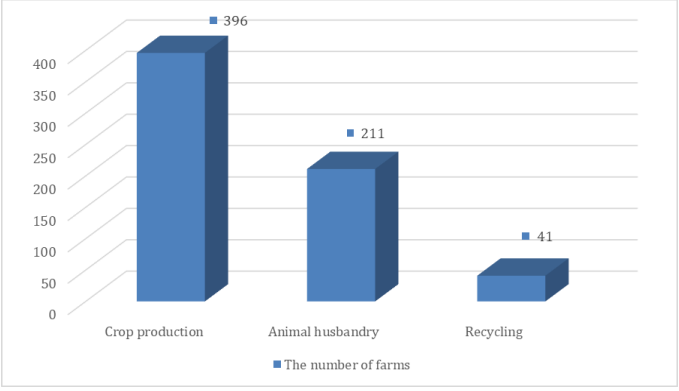


Figure 1 — The structure of farms using digital technologies and AI elements in Kazakhstan

Note: The authors calculated the data based on information from the Ministry of Agriculture of the Republic of Kazakhstan (2026). The shares were calculated only within a group of 648 farms and do not reflect the coverage of the entire agro-industrial complex.

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Additional institutional signals confirm the transition from local automation to integration. The updated map of the digital transformation of the agro-industrial complex provides for the digitisation of 144 business processes (Gosagro.kz. It unites more than 200,000 users; developing the e-APK should ensure data-driven industry management and AI adoption. OECD (2025) also emphasises integrating Kazakhstan's agricultural information systems into a single platform and developing crop traceability.

Table 3 — Factors of readiness of Kazakhstan's agro-industrial complex infrastructure for AI-control of logistics costs

Factor	Observed feature	Significance for cost control
Digitisation of processes	144 business processes	Standardisation of digital events
Unified ecosystem	e-APC and industry-specific Data Lake	Integration of data and analytics
Practical implementation	648 farms use digital technologies and AI	Base for pilot projects
Smart farming	More than 200 Smart farms	Sources of IoT/GPS/sensor data
Traceability	Scaling crop and livestock production systems	Linking a batch to a logistics event
Transport load	1,163.6 million tons of cargo; 584.3 billion ton-km	Importance of routing and loading
Note: compiled by the authors based on data from the Ministry of Agriculture of the Republic of Kazakhstan (2026a; 2026b), OECD (2025), and the Bureau of National Statistics (2026).		

The fourth result is an architecture of management control that fundamentally differs from the conventional model of digital transformation. Its starting point is not technology, but an accounting object. First, the company identifies the cost centre and the regulatory driver, then connects the operational data flow, and only then selects an AI algorithm. This approach reduces the risk of investing in a technology whose effect cannot be proven by accounting data.



Figure 2 — Architecture of AI-enabled control of logistics costs
Note: developed by the authors.

The architecture has five operational loops. The first collects event data from ERP, TMS, WMS, IoT, GPS, and traceability systems. The second is linking it

to cost centres and cost drivers. The third is AI analytics: forecasting, anomaly detection, classification, and optimisation. The fourth is the implementation of the solution in the logistics process. The fifth is plan–fact control. Actual deviations are returned to the model and used to update parameters, norms, and algorithms.

The fifth result is a methodology for prioritising AI projects. Given a limited investment budget, a company should not choose the "most advanced" technology, but rather a use case with the most clearly defined cause-and-effect relationship between the driver and the cost. We propose using four filters: the article's share in TLC; the driver's variability; the availability of digital data; and the process's controllability.

Table 4 — Logic for prioritising AI projects in agrilogistics

Situation	Priority AI Use Case	Rationale	Metrics Before/After Implementation
High transportation cost overruns	Route optimisation + ETA prediction	Direct driver of mileage and idle time	km per trip; vehicle load factor; transportation cost per tonne-km
High write-off rate	Quality analytics + cold-chain monitoring	Driven by time and temperature conditions	Loss rate; value of write-offs
Excess inventory	Demand forecasting + inventory optimisation	Driven by inventory volume and storage duration	Inventory turnover; inventory cost per unit
Frequent unplanned downtime	Predictive maintenance	Driven by unplanned equipment downtime	downtime hours; repair costs
High labour intensity of document processing	NLP/GenAI automation	Driven by manual processing time	minutes per document; administrative/AI cost per transaction
Note: Developed by the authors.			

The sixth result concerns the performance assessment system. To implement AI, we propose using not just a single ROI indicator, but a combination of operational, accounting, and investment levels. The operational level captures changes in the physical driver; the accounting level translates them into plan–actual deviations; the investment level compares savings with the technology's total cost of ownership.

Table 5 — KPI system for assessing AI in logistics costs

Level	Indicators	Purpose
Operational	km/trip; load factor; downtime hours; tonne-days of inventory; time outside the required temperature range	Measurement of changes in physical cost drivers
Accounting	TC/tonne-km; WC/tonne-day; IC/unit; LC/turnover; AIC/transaction	Assessment of the monetary effect
Service Quality	OTIF; lead time; stockout rate; return rate	Monitoring of service quality
Investment	TCO; payback period; ROI/NPV	Comparison of the achieved effect with implementation costs

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Risk/Data	share of missing data; data latency; manual adjustments	Assessment of the reliability of the digital data environment
Note: Developed by the authors with reference to Culot et al. (2024), Shahzadi et al. (2024), and Guidani et al. (2024).		

Discussion. The results change how the question about AI in logistics is framed: instead of "where can artificial intelligence be applied," the question becomes "what cost deviation needs to be monitored and what data allows for influencing it." This shifts the research from a general description of digitalisation to management accounting and controlling. This approach aligns with Spreitzenbarth et al.'s (2024) conclusion that cost analysis remains under-researched and complements the technological classifications of AI in SCM (Toorajipour et al., 2021; Richey et al., 2023).

It is essential to distinguish between price and operational effects. If fuel prices rise, transportation costs may increase even if routing improves. Therefore, assessing AI solely based on the dynamics of total logistics costs may be misleading. It is necessary to decompose the variance into price, volume, efficiency, and loss variances. Only the last two components can, in most cases, be directly linked to algorithmic management.

Including product losses in logistics cost control expands the traditional structure. For agricultural businesses, write-offs are often perceived as a separate category related to quality or production, although the cause may lie in logistics: loading delays, cold-chain disruptions, incorrect delivery sequence, or excessive storage. Research on agri-food digital twins and traceability confirms the need to track events throughout the entire chain (Guidani et al., 2024; Sebti et al., 2026). Consequently, cost traceability must develop in parallel with product traceability.

For Kazakhstan, the proposed methodology is particularly relevant now, as the digital infrastructure of the agro-industrial complex moves into the integration stage. The fact that 648 farms are already using digital technologies and AI elements does not mean the industry has completed its digitalisation. However, it does indicate a practical foundation for piloting cost-control solutions. At the same time, the relatively low level of processing in this group suggests a potential gap between digital production and the subsequent links in the chain.

An institutional transition to e-APK and an industry-specific Data Lake can improve the quality of external data for corporate AI systems. However, government integration does not replace the internal accounting architecture. The enterprise needs to ensure a unified cost centre directory, cost allocation rules, batch and transport identifiers, and consistency between ERP and TMS/WMS.

It is advisable to begin applying the model in processes where the cost of an error is high, and data is already being collected. In grain logistics, this includes transport loading, route, and waiting time; in the dairy and meat supply chains, it includes temperature control, traceability, and delivery time; in fruit and vegetable products, it includes demand forecasting, inventory rotation, and the risk of

write-offs. This sectoral choice aligns with the idea of AI portfolio management: the company forms a set of use cases based on economic priority.

The findings do not allow us to assert a universal savings amount. Studies on AI adoption highlight how outcomes depend on data quality, human capital, and organisational maturity (Shahzadi et al., 2024). Proper empirical verification should be carried out at the enterprise level using before–after, difference-in-differences, or panel data, provided there is a control group.

In scientific terms, the work connects two bodies of literature that often develop in parallel: AI-enabled supply chain and management accounting. The former explains how algorithms improve forecasting and optimisation, while the latter shows how changes in resources are reflected in costs and controls. Their integration makes it possible to move from a technological demonstration to the proof of economic impact.

Conclusion. The study showed that managing the logistics costs of the agro-industrial complex requires a fundamentally different approach to problem-solving than a general analysis of digital transformation. It is advisable to evaluate artificial intelligence based on its ability to modify a specific cost driver and ensure a measurable plan–actual deviation in the management accounting system.

The study identifies six blocks of total logistics cost: transportation, warehousing, inventory maintenance, cargo handling, product losses, and administrative and information costs. For each block, physical drivers, financial KPIs, and possible AI functions are identified. The proposed scheme "operational event → cost driver → cost centre → financial KPI → AI signal" forms a methodological interface between logistics systems and accounting.

Official data from Kazakhstan confirm the development of a technological base: 648 agricultural producers use digital technologies and AI elements; more than 200 enterprises are classified as Smart farms; the digital transformation roadmap includes digitising 144 business processes; e-APC and the industry-specific Data Lake are intended to create an integrated data environment. At the same time, Kazakhstan's transport system handled 1,163.6 million tons of cargo in 2025, with a cargo turnover of 584.3 billion ton-km, which underscores the economic significance of routing and load management tasks.

The practical contribution of the study lies in the methodology for selecting AI pilots. Priority should be determined not by the complexity of the technology, but by cost share, driver variability, data availability, and process controllability. Efficiency should be measured at three levels: changes in the physical driver, financial deviation, and investment performance, with total cost of ownership taken into account.

The key limitation is the lack of an open micro-database of logistics costs for agro-industrial enterprises in Kazakhstan. In this regard, the work deliberately excludes artificially generated regressions and unproven percentage savings. The

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next stage of the study should include obtaining anonymised ERP/TMS/WMS data from enterprises and empirically verifying the causal relationship between AI implementation and efficiency/loss variance. Promising methods include panel models, difference-in-differences, time-driven ABC, and analysis of digital traces of logistics events.

Thus, artificial intelligence in agri-logistics should be viewed not as an independent source of savings, but as a tool for changing the controllable cost drivers. The most sustainable effect is achieved when digital data, an algorithm, a logistics solution, and management accounting are combined into a single control loop.

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